

ETHANOL VEHICLES

Two vehicle models were tested on ethanol during this study: the FFV Ford Taurus and the FFV Chevrolet Lumina. The Taurus was tested at Lab 1 over two rounds and the Lumina was tested at Lab 2 over three rounds. Full hydrocarbon speciation was not performed on the Lumina emissions. The following sections of this report provide a detailed discussion of the results for both vehicles. A brief overview with a more qualitative

discussion of the results is presented in this section.

Table 22 and Table 23 provide a summary comparison of the average mass emissions and the hydrocarbon speciation, respectively, from E85 compared to RFG tests. As in the previous section on methanol, the shaded blocks represent a statistically significant difference (at the 95% confidence level) between average

Table 22. Summary Comparison of Average Emission Results from E85 versus RFG

	Ford Taurus Lab 1		Chevrolet Lumina Lab 2		
	Round 1	Round 2	Round 1	Round 2	Round 3
Regulated Emissions					
NMHCE	-	+	-	-	+
THC	+	+	-	+	-
CO	+	+	+	+	+
NO _x	-	+	-	-	-
Evaporative Emissions					
THC	-	+	-	-	-
Greenhouse Gases					
CO ₂	-	-	-	-	-
CH ₄	+	+	+	+	+
Aldehydes					
HCHO	+	+	+	+	+
CH ₃ CHO	+	+	+	+	+
Fuel Economy					
mpg	-	-	-	-	-
mpeg	+	+	+	+	+

“+” Indicates results from E85 tests were higher than RFG tests

“-” Indicates results from E85 tests were lower than RFG tests

Highlighted blocks indicate a significant statistical difference.

Table 23. Summary Comparison of Average Speciated Hydrocarbon Results for E85 versus RFG

	Ford Taurus
Air Toxics	Lab 1
HCHO	+
CH ₃ CHO	+
1,3-butadiene	-
Benzene	-
Total PWT	-
Ozone Reactivity	
OFP	+
SR	-

results from the two fuels. A plus sign indicates that the average E85 results were higher, and a minus sign indicates that the average E85 results were lower than the RFG results.

The most obvious trend displayed in Table 22 is that the comparison of non-regulated emissions (greenhouse gases, aldehydes, and fuel economy) tended to be consistent across test rounds and vehicle types, and the differences tended to be statistically significant. Average CO₂ and mpg were consistently lower when tested on E85 compared to RFG. Average aldehydes (HCHO and CH₃CHO) and gasoline equivalent fuel economy (mpeg) were consistently higher from the E85 tests compared to the RFG tests. On the other hand, the comparison of average regulated emissions results tended to be less consistent.

Results from the FFV Taurus tended to show higher regulated emissions from E85, but the differences were not statistically significant. For the Lumina, some of the regulated emissions were significantly lower on E85 (NO_x), some tended to be significantly higher (CO), and others were mixed from round to round (THC and NMHCE).

Similar to the methanol vehicles, the ethanol vehicles are flexible-fuel designs that are not fully optimized for either gasoline or ethanol. The differences in results between vehicle models and the lack of clear regulated emissions differences may result, in part, from engine hardware choices and calibrations that must be flexible to accommodate a wide range of fuel blends.

The results from the detailed speciation of hydrocarbon emissions on the Taurus are summarized in Table 23. This table combines the results from the two rounds because the difference between the two rounds was not significant. The general trends that are evident in Table 23 include:

- Average aldehyde emissions (HCHO and CH_3CHO) tended to be higher from the E85 tests compared to the RFG tests
- Average 1,3-butadiene, benzene, and total PWT emissions tended to be significantly lower from the E85 tests compared to the RFG tests
- Average OFP tended to be higher, but SR tended to be significantly lower from the E85 tests compared to the RFG tests.

This last point was a bit surprising and deserves additional explanation. Although the OFP (expressed in milligrams of ozone per mile) was higher for the ethanol tests, the SR (expressed in terms of milligrams of

ozone per milligram of non-methane organic gases) was lower. This was the case because, although the hydrocarbon emissions from the E85 tests were significantly less reactive, the total hydrocarbons from this subset of test vehicles were significantly higher when tested on E85 compared to the same vehicles tested on RFG. However, this was not the case for the larger sample of test vehicles. As was mentioned earlier, for all the Ford Taurus test vehicles, there was not a statistically significant difference between the average NMHCE emissions from E85 compared to the same vehicles tested on RFG.

FORD TAURUS

The 1995 FFV Ford Taurus (Figure 20) tested in this project was actually designed to run on methanol, but GSA obtained approval to operate the vehicles on ethanol. The Taurus is a passenger car equipped with a 3.0 L V6 engine. The FFV Taurus was certified to transitional low emission vehicle (TLEV) standards and the gasoline model was certified to EPA Tier 1 levels (Table 1). Two rounds of testing were completed on the FFV Ford Taurus at Lab 1. There were 14 FFV Tauruses and 16 gasoline controls tested in both rounds. Mileage ranges and average odometer



Argonne National Laboratory/PIXO

Figure 20. The 1995 E85 Ford Taurus

Table 24. Odometer Readings for the Ford Taurus

	FFV		Gasoline	
Round	1	2	1	2
No. vehicles tested	14	14	16	16
Odometer (miles)				
Average	5,069	16,095	4,859	14,201
Maximum	10,253	29,184	12,822	31,503
Minimum	3,067	8,158	3,027	8,055

readings for the Taurus are listed in Table 24. The complete data set for the Taurus is found in Appendix A.

Regulated Emissions

Table 25 shows the average emissions results for the FFV Ford Taurus. Figure 21 illustrates the average regulated emissions and CO₂ values. In general, when comparing the regulated emissions from the FFV Taurus tested on E85 to the same vehicles tested on RFG, there was no significant difference between fuels. In Round 1, the emissions levels from the FFV on E85 and RFG were similar to the conventional Taurus tested on RFG. In Round 2, the FFV on E85 had slightly higher values for all three regulated compounds.

When comparing the NMHCE emissions for the Taurus (Figure 21a),

there was not a significant difference between the FFV on either fuel and the conventional model for Round 1. In Round 2, the NMHCE emissions for the FFV on E85 were 12.5% higher than on RFG, but this difference was not significant at the 95% confidence level. The average for the standard model in Round 2 was lower than the FFV on both fuels. All these values were below the Tier 1 limit of 0.25 g/mi. The FFV Taurus is certified to the TLEV emissions standard, which is written in terms of NMOG (see explanation on page 1). Although NMOG was not evaluated for the entire set of vehicles, it appears that the FFV in Round 2 exceeded the TLEV standard.

When comparing the average CO emissions for the Taurus (Figure 21b), the FFV on E85 had slightly higher values than the same vehicles

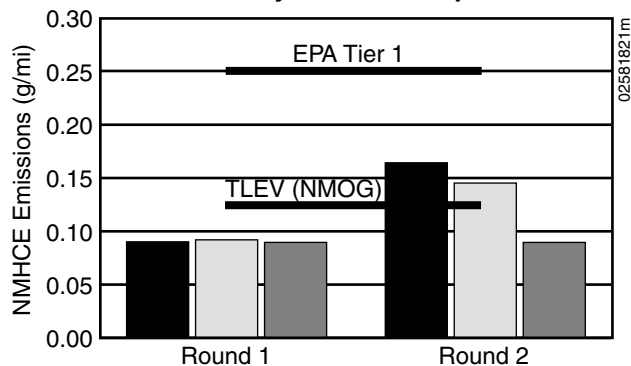
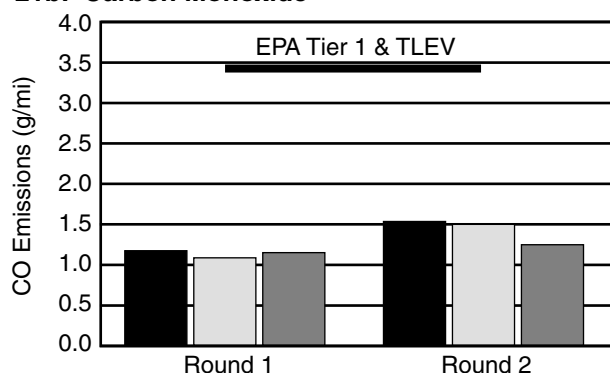
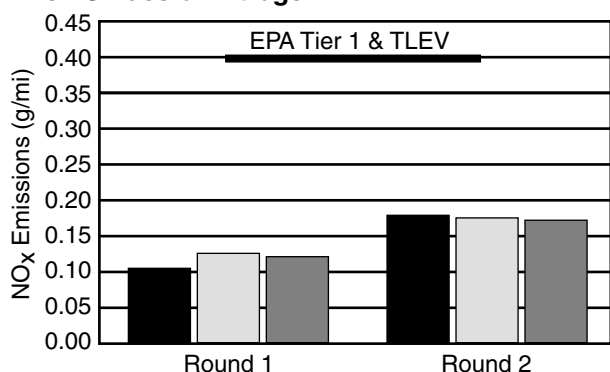
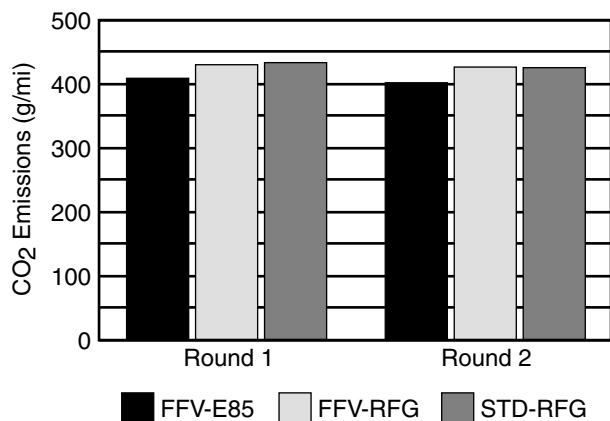
tested on RFG in both rounds, but the difference was not statistically significant at the 95% confidence level.

In Round 1, the increase for the FFV tested on E85 was 8% higher and in Round 2 the average was approximately 2% higher. Once again, all averages were well below the Tier 1 and TLEV limit of 3.4 g/mi.

NO_x emissions for the Taurus are shown in Figure 21c. When comparing the FFV on E85 to the same vehicles on RFG, there was a decrease in average NO_x in Round 1, but an increase in Round 2. Neither of these differences was statistically significant, and all values remained well below the Tier 1 and TLEV limit of 0.4 g/mi. The averages for all three regulated compounds showed significant increases from Round 1 to Round 2, but all were below the Tier 1 certification limit.

Table 25. Average Emissions Results from the Ford Taurus

	Round 1				Round 2			
	FFV-E85	FFV-RFG	Percent Difference	Sig. Fuel Effect?	FFV-E85	FFV-RFG	Percent Difference	Sig. Fuel Effect?
Regulated Emissions (g/mi)								
NMHCE	0.089	0.091	-2.2%	n	0.163	0.144	12.5%	n
THC	0.103	0.101	2.4%	n	0.184	0.156	17.9%	y
CO	1.162	1.075	8.1%	n	1.522	1.486	2.4%	n
NO _x	0.104	0.125	-16.8%	n	0.183	0.178	2.8%	n
Evaporative Emissions (g/test)								
Total Evaporative	0.328	0.332	-1.2%	n	0.362	0.319	13.5%	n
Greenhouse Gases (g/mi)								
CO ₂	405.5	426.5	-4.9%	y	398.5	422.9	-5.8%	y
CH ₄	0.025	0.012	107.4%	y	0.035	0.016	122.9%	y
Aldehydes (mg/mi)								
HCHO	2.03	1.29	57.4%	y	2.96	1.54	92.2%	y
CH ₃ CHO	9.0	0.37	2332.4%	y	13.6	0.37	3575.7%	y
Fuel Economy								
mpg	15.22	20.4	-25.4%	y	15.46	20.49	-24.6%	y
mpeg	20.82	20.4	2.1%	y	21.15	20.49	3.2%	y

21a: Non-Methane Hydrocarbon Equivalent**21b: Carbon Monoxide****21c: Oxides of Nitrogen****21d: Carbon Dioxide****Figure 21. Emissions results from the Ford Taurus**

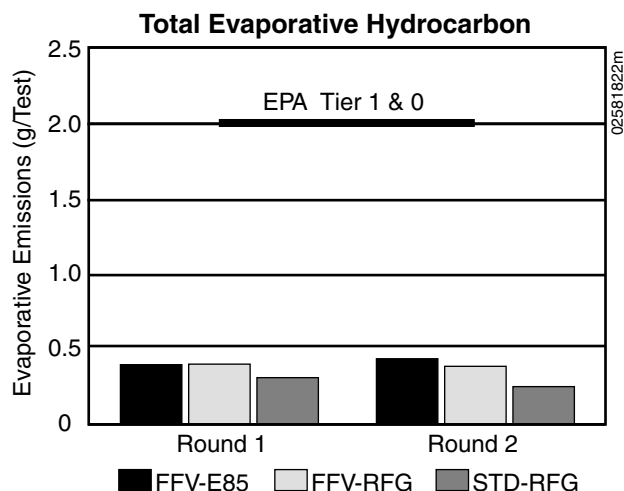
Evaporative Emissions

Figure 22 shows the comparison of the average evaporative emissions for the Taurus. Evaporative emissions for the FFV on both fuels and the conventional Tauruses were well below the EPA limit of 2 g of hydrocarbon per test. When comparing the evaporative emissions for the FFV Taurus, there was not a significant difference in the FFV tested on E85 and the same vehicles tested on RFG. The conventional Taurus had lower average evaporative emissions than the FFV on either fuel. The round-to-round comparison for the FFV showed a small increase for the E85 tests, and a small decrease for the RFG tests. Neither of these differences was statistically significant at the 95% confidence level.

Greenhouse Gases

Carbon dioxide emissions for the Taurus are shown in Figure 21d. When comparing the FFV on E85 to the same vehicles tested on RFG, the E85 CO₂ emissions were approximately 5% lower in both rounds. This difference was statistically significant at the 95% confidence level. The conventional Taurus tested on RFG showed very similar values to the FFV tested on RFG. There was a small decrease in CO₂ emissions for Round 2 that was statistically significant for both fuels.

Methane emissions for the FFV tested on E85 were significantly higher than when the same vehicles were tested on RFG. The average CH₄ emissions were 107% higher in Round 1 and 123% higher in Round 2. It is important to note, however, that the values for both fuels are very small (0.012 to 0.035 g/mi). There was a small increase in CH₄ emissions from Round 1 to Round 2 that was significant for both fuels.

**Figure 22. Evaporative emissions results from the Ford Taurus**

Aldehydes

Aldehyde emissions for the Ford Taurus are shown in Figure 23. Formaldehyde emissions were higher for the FFV tested on E85 in both rounds. The percent difference between the FFV tested on E85 and the same vehicles tested on RFG was 57% for Round 1 and 92.2% for Round 2. Acetaldehyde is a primary decomposition product from ethanol combustion; therefore, the much higher values were expected when the vehicle was operating on E85. The percent increase in the FFV acetaldehyde emissions when tested on E85 was 2,332% for Round 1 and 3,575% for Round 2. The acetaldehyde levels for RFG were very low—less than 0.5 mg/mi. Although both fuels show increases in aldehyde emissions from Round 1 to Round 2, only the increases for the E85 tests were statistically significant.

Potency-Weighted Toxics and Ozone-Forming Potential

During this project, full hydrocarbon speciation was performed on six of the FFVs and five of the standard Tauruses. Table 26 summarizes the average measured toxic emissions and the PWT results for the Taurus. When comparing the FFV tested on E85 to the same vehicles tested on RFG, there were significant increases in aldehyde emissions and significant decreases in 1,3-butadiene and

benzene. Figure 24 shows this difference graphically. Although the total measured toxics were higher, the potency weighted values were significantly lower for the E85 tests. Total PWT for the FFV tested on E85 were 44% lower than the same vehicles tested on RFG. Although acetaldehyde is the highest measured value for E85 tests, it is the least toxic of the four. The conventional model tested on RFG showed results similar to the FFV tested on RFG.

Table 27 and Figure 25 show the NMOG, OFP, and SR results for the Taurus. The OFP for the FFV tested on E85 was significantly higher (19%) than the same vehicles tested on RFG, but the SR was significantly lower (approximately 38%) for the E85 tests. The OFP for the FFV

tested on E85 was higher than the same vehicles tested on RFG because the total HC from this subset of vehicles were substantially higher. The lower SR indicates that the FFV tested on E85 was less reactive per unit mass.

Fuel Economy

Table 25 gives the actual and equivalent fuel economy for the FFV Ford Taurus. Average fuel economy for the FFV Taurus on E85 was approximately 15 mpg. The average when tested on RFG was approximately 25% higher, at 20 mpg. As with methanol, E85 has a lower volumetric energy content than RFG. The volumetric energy content for E85 (81,825 Btu/gal) is approximately 73% of RFG (111,960 Btu/gal). This

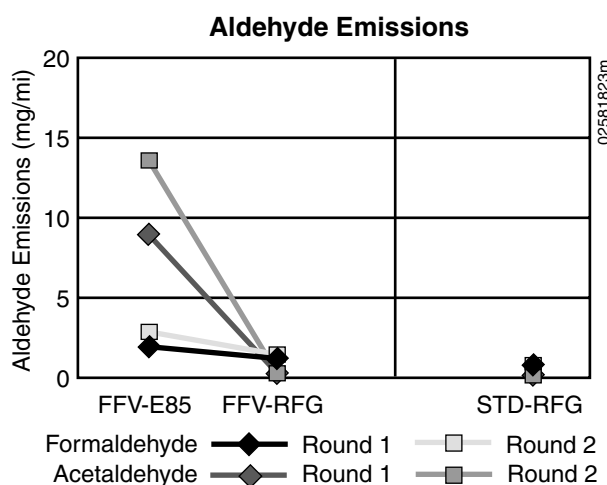


Figure 23. Aldehyde emissions from the Ford Taurus

Table 26. Toxic Emissions from the Ford Taurus

	FFV-E85		FFV-RFG		Percent Difference	Sig. Fuel Effect?
	Measured Value (mg/mi)	PWT	Measured Value (mg/mi)	PWT		
HCHO	2.223	0.102	1.30	0.06	70.9%	y
CH ₃ CHO	9.854	0.079	0.275	0.002	3,490.9%	y
1,3-butadiene	0.175	0.175	0.544	0.544	-67.8%	y
Benzene	1.013	0.03	2.863	0.086	-65.1%	y
Total	13.265	0.386	4.982	0.692	-44.2%	y

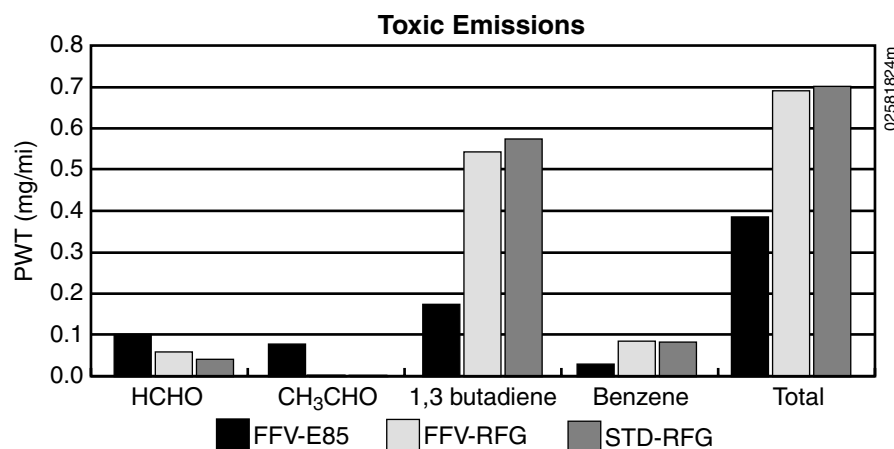


Figure 24. PWT emissions from the Ford Taurus

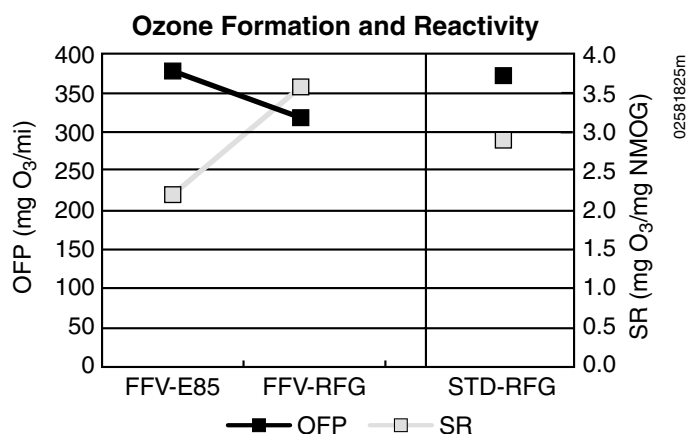


Figure 25. OFP and SR for the Ford Taurus

Table 27. OFP for the Ford Taurus

	FFV-E85	FFV-RFG	Percent Difference	Sig. Fuel Effect?
NMOG (mg/mi)	171.97	92.30	86.3%	y
OFP (mg O ₃ /mi)	377.58	318.06	18.7%	y
SR (mg O ₃ /mg NMOG)	2.215	3.57	-38.0%	y

means that it takes 1.3 gallons of E85 to travel the same distance as 1 gallon of gasoline. On an energy equivalent basis, the FFV Taurus was 2% to 3% more energy efficient when tested on E85. Like the Spirit, the fuel tank of the FFV Taurus was increased to account for the differing energy content of the fuel. The gasoline Taurus has a 16-gallon tank for a range of approximately 326 miles. The FFV has a tank that holds 20.4 gallons for

a range of 313 miles on E85 and 417 miles on gasoline.

CHEVROLET LUMINA

The 1993 FFV Chevrolet Lumina (shown in Figure 26) is a passenger car equipped with a 3.1 L V6 engine with multi-point fuel injection. The Lumina was certified to EPA federal Tier 0 emissions levels. This report covers the three rounds of testing completed on the Chevrolet Lumina

at Lab 2. Ten FFV Luminas and 11 gasoline controls were tested in all 3 rounds. Mileage ranges and average odometer readings for the Lumina are listed in Table 28. Lab 1 tested a limited number of FFV Lumina during Round 1 only. The results for those tests were reported in another publication and are not included in this paper.⁹ Hydrocarbon speciation was not performed on the vehicles included in this analysis. The entire data set is located in Appendix A.

Regulated Emissions

The average emissions results for the Lumina are listed in Table 29. The regulated and CO₂ emissions for the FFV Lumina are shown in Figure 27. In general, when comparing the FFV tested on E85 to the same vehicles tested on RFG, there tended to be a slight decrease in NMHCE, a larger decrease in NO_x, and an increase in CO emissions. The average regulated emissions for the FFV Lumina were all well below the Tier 0 standard, as well as the more stringent Tier 1 standard, shown here for reference. The regulated emissions for the gasoline model did not follow the same trend. NMHCE and NO_x emissions for the gasoline Lumina were below the Tier 0 levels, but CO emissions were over the limit for all 3 rounds.

Although NMHCE values for the FFV tested on E85 were lower than the RFG tests in Rounds 1 and 2 (see Figure 27a), the difference was not significant in Round 2. There was no significant difference in NMHCE emissions between the two fuels for Round 3. All the values for the FFV Lumina were below the EPA Tier 1 limit of 0.25 g/mi. Round-to-round comparison for the E85 tests showed an increase in NMHCE over time that was statistically significant. The smaller increase in NMHCE for the RFG tests on the FFV was not statistically significant at the 95% confidence level. The standard gasoline

model showed a small but significant increase in each round.

CO emissions follow a different trend than NMHCE (Figure 27b). In all three rounds, the FFV tested on E85 showed higher CO emissions than when the same vehicles were tested on RFG. The percent increases were 7.5% for Round 1, 33% for Round 2, and 22% for Round 3. This increase was statistically significant for Rounds 2 and 3, but not for Round 1. The standard gasoline model tested significantly higher than the FFV on either fuel. The average CO for the FFV tested on E85 and RFG were below the Tier 0 emissions standard, but the gasoline Lumina exceeded the limit for all three rounds. The Round 3 average for the gasoline Lumina was approximately 50% higher than the 3.4 g/mi standard.

NO_x emissions for the FFV tested on E85 were significantly lower than those from the same vehicles tested on RFG for all 3 rounds. There was a decrease of 40%, 37%, and 34% for Rounds 1, 2, and 3, respectively. As with the CO emissions, NO_x averages for the standard model were much higher than the averages for the FFV. Both the FFV tested on E85 and RFG and the standard model tested on RFG had NO_x levels below the Tier 0 standard of 1 g/mi. The FFV on each fuel was also below the more stringent Tier 1 level.

Evaporative Emissions

Evaporative emissions for the FFV Lumina are listed in Table 29 and graphically illustrated in Figure 28. When comparing the average evaporative emissions for the FFV tested on E85 to the averages for the same vehicles tested on RFG, there was a small reduction in evaporative emissions for all three rounds. However, only the reduction for Round 2 was statistically significant. The conventional Lumina tested higher than



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Figure 26. The 1993 E85 Chevrolet Lumina

Table 28. Odometer Readings for the Chevrolet Lumina

	FFV			Gasoline		
Round	1	2	3	1	2	3
No. vehicles tested	10	10	10	11	11	11
Odometer (miles)						
Average	10,111	22,568	30,883	6,344	12,434	19,403
Maximum	12,409	35,842	42,538	10,713	18,970	37,902
Minimum	8,218	12,991	19,700	2,903	6,826	11,365

the FFV on both fuels. All averages were well below the 2 g per test standard. Round-to-round differences show small increases over time for the FFV on both fuels. These differences tended not to be significant at the 95% confidence level.

Greenhouse Gases

Figure 27d shows the average CO₂ emissions levels for the Lumina. The CO₂ average for the FFV tested on E85 was approximately 6% lower than when tested on RFG in all three rounds. These differences were all statistically significant at the 95% confidence level. CO₂ emissions for the standard Lumina tested on RFG

were lower than the FFV on RFG. Round-to-round comparisons for the FFV tested on E85 and RFG showed significant decreases in CO₂ during Round 2 and significant increases in Round 3. This held true for both the E85 and RFG tests on the FFV Lumina.

Although emissions of CH₄ for the FFV are small (less than 0.08 g/mi), the results for the tests on E85 are significantly higher than those from the RFG tests. Round-to-round comparisons of CH₄ emissions for the E85 tests show a small but significant increase in Round 2 and a small but significant decrease in Round 3. The FFV tests with RFG show no

Table 29. Average Emissions Results from the Chevrolet Lumina

	Round 1				Round 2				Round 3			
	FFV E85	FFV RFG	Percent Difference	Sig. Fuel Effect?	FFV E85	FFV RFG	Percent Difference	Sig. Fuel Effect?	FFV E85	FFV RFG	Percent Difference	Sig. Fuel Effect?
Regulated Emissions (g/mi)												
NMHCE	0.087	0.102	-14.7%	y	0.105	0.109	-3.7%	n	0.118	0.117	0.8%	n
THC	0.106	0.125	-14.5%	y	0.140	0.134	4.5%	n	0.141	0.1414	-0.3%	n
CO	2.22	2.07	7.5%	n	3.08	2.32	32.9%	y	2.84	2.33	21.3%	y
NO _x	0.156	0.261	-40.4%	y	0.206	0.329	-37.4%	y	0.233	0.352	-34.1%	y
Evaporative Emissions (g/test)												
Total Evaporative	0.153	0.162	-5.6%	n	0.159	0.242	-34.3%	y	0.163	0.207	-21.3%	n
Greenhouse Gases (g/mi)												
CO ₂	454.2	485.9	-6.5%	y	435.9	462.5	-5.7%	y	443.9	468.9	-5.3%	y
CH ₄	0.056	0.028	100%	y	0.074	0.031	141.6%	y	0.066	0.031	110.6%	y
Aldehydes (mg/mi)												
HCHO	6.98	4.66	49.8%	y	5.56	3.92	41.8%	y	5.38	3.36	60.1%	y
CH ₃ CHO	18.08	0.73	2482.9%	y	17.04	0.78	2030%	y	17.98	0.70	2468.6%	y
Fuel Economy												
mpg	13.57	18.09	-25.0%	y	14.1	18.99	-25.8%	y	13.86	18.72	-26%	y
mpeg	18.57	18.09	2.6%	y	19.29	18.99	1.6%	y	18.96	18.72	1.3%	y

significant difference between rounds. Average CH₄ values for the gasoline Lumina also show no significant difference between rounds.

Aldehydes

Aldehyde emissions for the Lumina are shown in Figure 29. Formaldehyde emissions from the FFV tested on E85 were significantly higher than those from the same vehicles tested on RFG. In Round 1, formaldehyde emissions from the FFV on E85 were 50% higher than those from RFG, Round 2 results were 42% higher, and Round 3 results were 60% higher. Formaldehyde emissions for the standard Lumina were higher than those from the FFV on RFG, but lower than those from the FFV on E85. The average acetaldehyde (a primary decomposition product of ethanol combustion) emissions for

the FFV tested on E85 were 2,483%, 2,030%, and 2,469% higher than those from the same vehicles tested on RFG, respectively. The differences between rounds were not statistically significant.

Potency-Weighted Toxics and Ozone -Forming Potential

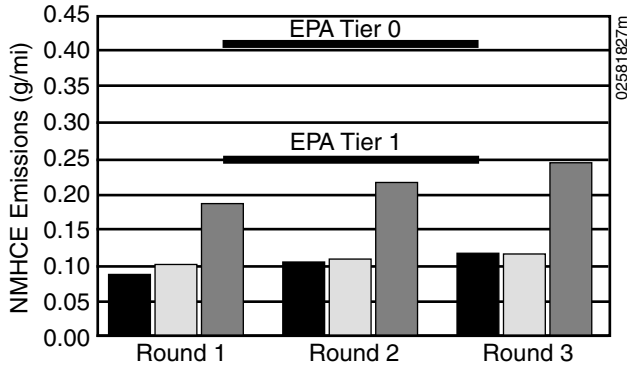
Because full hydrocarbon speciation was not performed on the Lumina during this project, PWT and OFP were not evaluated.

Fuel Economy

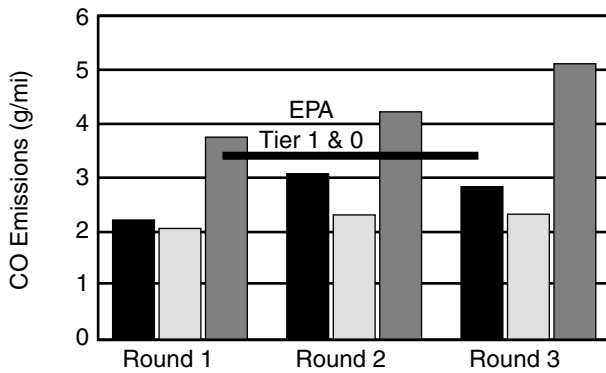
Table 29 gives actual and equivalent fuel economy for the FFV Lumina. Actual fuel economy for the Lumina tested on E85 over the 3 rounds ranged from 13.5 to 14 mpg. This was 25% to 26% lower than the same vehicles when tested on RFG. The standard models tested slightly higher

than the FFV on RFG. Because of the difference in energy content between E85 and RFG, gasoline energy equivalent fuel economy was calculated for the E85 tests. The energy equivalent fuel economy for the E85 tests ranged from 18.6 mpeg to 19.3 mpeg. Taking this into account, the fuel economy for the FFV tested on E85 was 1.3% to 2.6% higher than when tested on RFG. The fuel tanks for the gasoline and FFV Lumina are similar in size. The gasoline Lumina has a tank that holds 17.1 gallons for a range of approximately 330 miles. The FFV Lumina has a 16.5-gallon fuel tank for a range of 228 miles on E85 and 306 miles on gasoline.

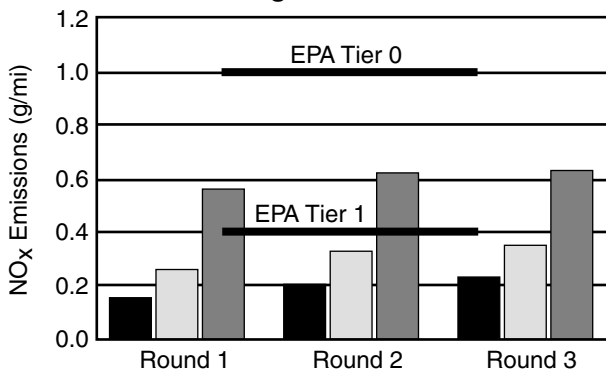
27a: Non-Methane Hydrocarbon Equivalent



27b: Carbon Monoxide



27c: Oxides of Nitrogen



27d: Carbon Dioxide

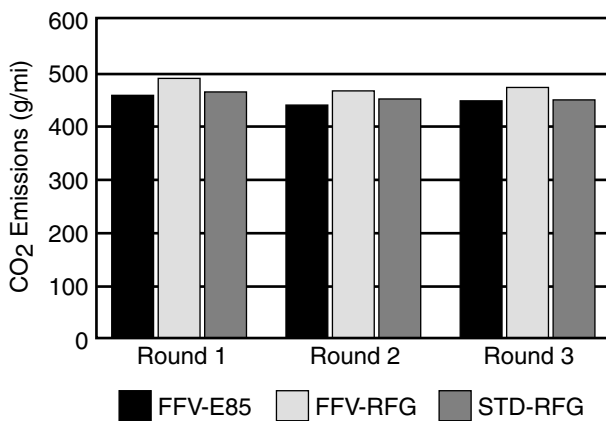


Figure 27. Emissions results from the Chevrolet Lumina

Total Evaporative Hydrocarbon

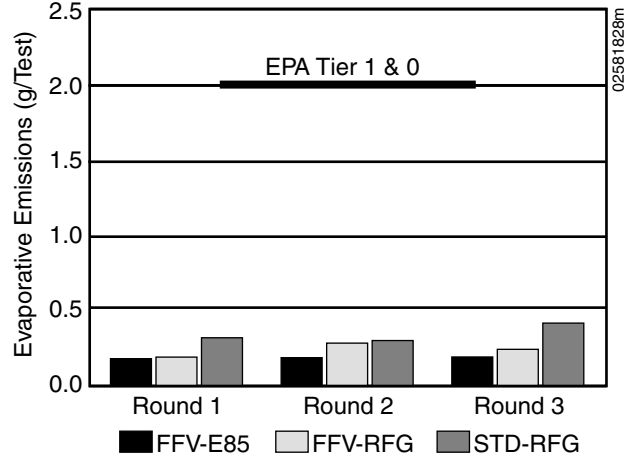


Figure 28. Evaporative emissions results from the Chevrolet Lumina

Aldehyde Emissions

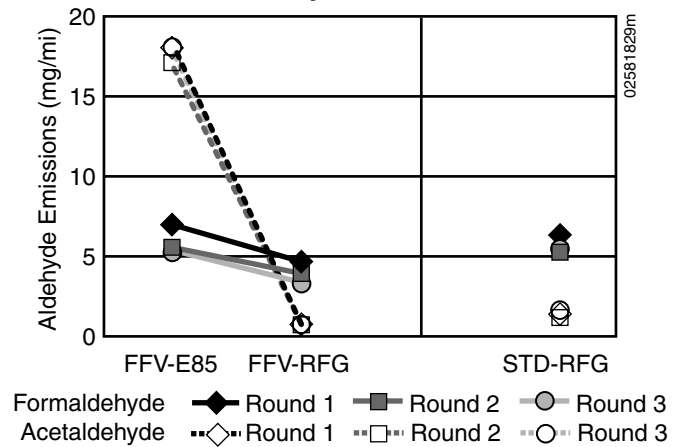


Figure 29. Aldehyde emissions from the Chevrolet Lumina